Journal of Forensic and Legal Medicine 19 (2012) 162–167

Contents lists available at SciVerse ScienceDirect

Journal of Forensic and Legal Medicine

journal homepage: www.elsevier.com/locate/jflm

Original communication

Sex estimation from foramen magnum dimensions in an Indian population

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ARTICLE INFO

Article history:
Received 1 December 2011
Accepted 27 December 2011
Available online 17 January 2012

Keywords:
Forensic science
Forensic anthropology
Identification
Sex estimation
Skull
Foramen magnum

ABSTRACT

Identification of skeletal remains is vital in forensic investigations. The need for methods to estimate sex from cranial fragments becomes apparent when only a part of skull is brought for identification. The present research is an attempt to study the sexual dimorphism of the anteroposterior diameter, transverse diameter and area of foramen magnum in a population of costal Karnataka region using statistical considerations. Ninety adult dry skulls of known sex (50 male and 40 female) were included in the study. Morphometric analysis of foramen magnum was conducted using vernier calipers and the area of foramen magnum was calculated. The anteroposterior diameter, transverse diameter and area of foramen magnum are found to be significantly larger in males than females. Binary Logistic Regression (BLR) analysis was performed to derive models for estimation of sex from the different measurements of foramen magnum and Receiver Operating Characteristic (ROC) curve was drawn for the predicted probabilities obtained from BLR analysis. The predictability of foramen magnum measurements in sexing of crania was 65.4% for transverse diameter and 86.5% for the anteroposterior diameter. For the area of foramen magnum that was calculated using the formula derived by Radinsky and Teixeria, the predicted probabilities were observed to be 81.6% and 82.2% respectively. When anteroposterior and transverse diameter were used together in BLR analysis the predictability of sex increased to 88%. However, considering the overlapping in the male and female values for the foramen magnum measurements it is suggested that its application in sex estimation should be restricted to cases where only a fragment of base of the skull is brought for examination. In such cases, the anteroposterior diameter and area of the foramen magnum can be employed as better tools for sexing the skulls than the transverse diameter of the foramen magnum.

1. Introduction

The successful identification of the deceased is vital to any forensic investigation. One of the principal biological traits to be estimated from skeletal remains is the sex of the individual. Anthropological analysis is the mainstay in estimation of sex of unknown skeletal remains. Skeletal sex estimation relies on the sexually dimorphic expression of bony characteristics that are produced through different patterns, rates and periods of adolescent growth.[1] Sex can be estimated from a gross examination of the skeleton using metric and morphological techniques. Krogman in an admittedly biased study estimated sex with 100% accuracy when the whole skeleton was present, 98% from pelvis and cranium, 95% with only pelvis or pelvis and long bones, and 80–90% when only long bones or skull alone is brought for examination.[2] Later Stewart stated a sexing accuracy of 90–95% from whole skeleton, pelvis, or one hip bone, and 80% accuracy from skull alone.[3,4] Sex estimation in the human cranium is generally based on size differences and robusticity.[1,5] The differences are population specific and can be influenced by genetic, environmental and social factors.[6,7] Various studies have been done in the past to estimate the sex with reasonable accuracy by employing different measurements of cranium.[8–11] In a study on evaluation of accuracy and precision of cranial morphological traits for estimation of sex, William and Rogers considered more than 80% as the acceptable limits of accuracy.[12]

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doi:10.1016/j.jflm.2011.12.019

Sex estimation becomes more difficult if only fragments of a skull are brought for medicolegal examination. Such fragmented skulls may be encountered in cases of physical insults such as fire, explosions or violence. The basal region of the occipital bone is covered by a larger volume of soft tissue. Owing to its thickness and relatively well-protected anatomical position, the basal region of the occipital bone is more likely to survive the physical insults than the other parts of skull. Thus, studies on estimation of sex using the occipital bone may prove useful in cases of identification of significantly disrupted remains.[5] Teixeria published an initial study on estimation of sex based on the size of foramen magnum.[13] Subsequent studies on this subject have been conducted on British,[5] Central European[14] Turkish[15,16] and Indian populations[17–19] using different statistical considerations. Gapert et al[5] used discriminant function and regression analysis on an eighteenth and nineteenth century British sample. The discriminant functions developed in the study predicted correct sex in 70.3% of all cases. Gruber et al[14] did not find any sexual dimorphism in the diameters of foramen magnum in Central European dry specimen dating from Pleistocene to modern times. Uysal et al have reported statistically significant sex differences in the width of foramen magnum diameters by using three-dimensional computed tomography (3DCT) measurements[16] and Gunay and Altinkok[15] based on correlation coefficient analysis concluded that the area is not a useful indicator for sex estimation in a Turkish population. In previous studies on Indian populations, Routal et al[17] and Sayee et al[18] utilized identification points (IP) and demarking points (DP) analysis while Deshmukh and Devershi[19] used univariate analysis. These studies did not find the foramen magnum measurements as reliable sexing criteria.

The principle aim of the present research is to study the sexual dimorphism of the anteroposterior diameter, transverse diameter and area of foramen magnum in a population from coastal Karnataka region using statistical considerations and to evaluate whether the foramen magnum morphometry can be reliably employed as a tool for forensic identification when only a fragment of base of the skull is brought for identification.

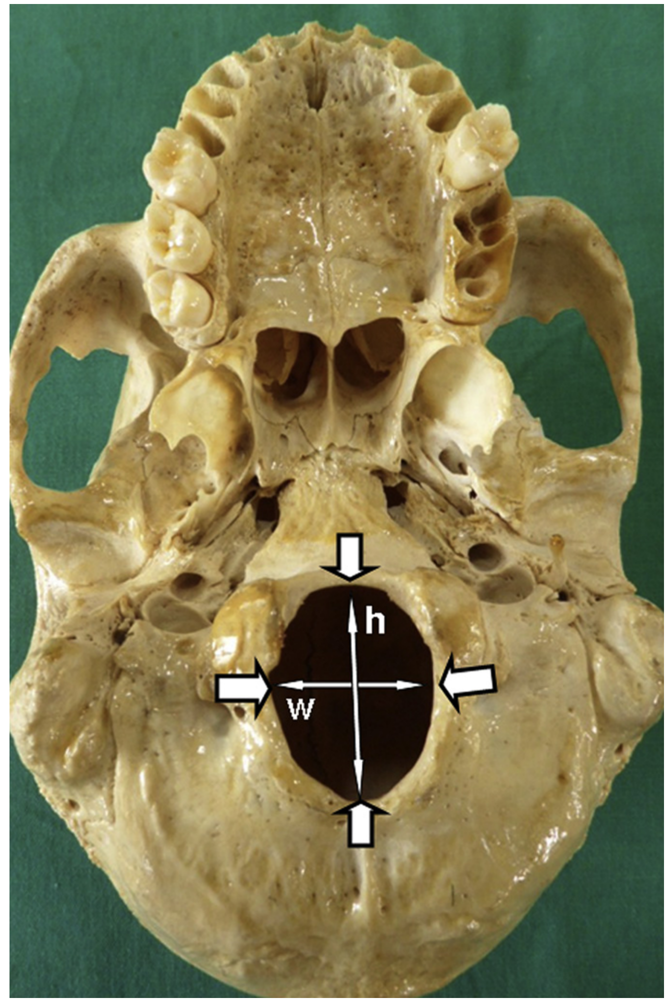

Fig. 1. Landmarks of foramen magnum illustrated on the base of skull.

2. Materials and methods

The present research was a short term time bound project conducted in the Department of Forensic Medicine, Kasturba Medical College, Mangalore. Ninety adult dry skulls (50 males and 40 females) were included in the study. The skulls were free from any fracture or other deformities. Morphometric analysis on the occipital bones was conducted with Vernier calipers (Lianying 0005) graduated to the last 0.01 mm.

2.1. *Techniques for taking anthropometric measurements and measuring the area of the foramen magnum*

Landmarks on the foramen magnum are described in Fig. 1.

2.1.1. *Foramen magnum length/Anteroposterior diameter (h)*

Foramen magnum length/Anteroposterior diameter (h) is the distance between Basion and Opisthion. Basion is the point where the anterior margin of the foramen magnum is intersected by the mid–saggital plane and Opisthion is the point at which the mid–saggital plane intersects the posterior margin of the foramen magnum.

2.1.2. *Foramen magnum breadth/Transverse diameter (w)*

Foramen magnum breadth/Transverse diameter (w) is the distance between the lateral margins of the foramen magnum at the point of greatest lateral curvature.

The prongs of the vernier calipers were placed over the described landmarks, fixed manually with the screw provided and the length and breadth of foramen magnum were recorded over the graduated metallic scale on the calipers itself.

2.1.3. *The area of the foramen magnum (A)*

The area of the foramen magnum (A) was calculated using formula derived by Radinsky[20] and Teixeria.[13]

$$\text{Radinsky's formula}: A = 1/4 \times \pi \times w \times h$$
$$\text{Teixeria's formula}: A = \pi \times \{(h+w)/4\}^2$$

(In the formula, 'π' was substituted as 22/7).

Before taking up the study, the measurements (h) and (w) were taken on 10 skulls by two observers (RBYP and TK) and tested for inter-observer error in measurements. TK measured the same skulls again for 'h' and 'w' two days later to find the intra-observer error in measurements. Both inter-observer and intra-observer error were estimated using paired t-test. No significant inter-observer error ($t = -0.557$, $p = 0.591$ for 'h', and $t = -1.464$, $p = 0.177$ for 'w') and intra-observer error ($t = -0.361$, $p = 0.726$ for 'h', and $t = -1.152$, $p = 0.279$) were found for the measurements of foramen magnum.

The data was analyzed using SPSS (Statistical Package for Social Sciences, version 11.0) computer software (SPSS, Inc., Chicago, IL, USA). Male–female differences in measurements were tested using

Table 1
Descriptive statistics: Measurements of the foramen magnum.

	Male ($n = 50$)		Female ($n = 40$)			
	Range	Mean (S.D)	Range	Mean (S.D)	Z-value	p-value
h	30.5–38.9	35.68(1.77)	29.7–37.7	32.57(2.08)	−5.930	<0.001
w	24.1–32.5	28.91(1.62)	24.7–32.8	28.19(1.76)	−2.495	0.013
A (R)	613.49–923.67	811.67(69.90)	595.06–927.77	722.66(78.20)	−5.132	<0.001
A (T)	618.20–932.49	821.36(70.10)	598.53–929.78	727.31(78.70)	−5.230	<0.001

h – Anteroposterior diameter (mm), w – Transverse diameter (mm), A – Area (mm^2), S.D. – Standard Deviation, (R) – Radinsky's formula, (T) – Teixeria's formula.

Mann–Whitney U test. Paired t-test was used to observe the differences between the area of foramen magnum determined by formula derived by Radinsky[20] and Teixeria.[13] Binary Logistic Regression (BLR) analysis was done to derive a predicting equation for estimation of sex from the different variables. On utilization of BLR models derived in the study all positive values (zero and above) were considered as females and negative values (less than zero) as males. Receiver Operating Characteristic (ROC) curve was drawn for the predicted probabilities obtained from BLR analysis. ROC curve provides a measure of a model's ability to discriminate two groups. From the BLR analysis the predicted probabilities are drawn and a predicted value is obtained for each case. These values are compared with the original values and sensitivity and the specificity is calculated. The sensitivity and the specificity is thus, calculated from the original gender data with that of the predicted one. Area under the ROC curve denotes the predictability of each variable (h, w, A) in sex estimation. When the area under the curve closer to 1 it is predicted that the model discriminates two groups well. In the study, statistical significance (p-value) was defined as $\alpha = 0.05$.

3. Results

Descriptive statistics for the foramen magnum measurements and area in males and females are shown in Table 1. The length, breadth, and the area of foramen magnum are found to be higher in males than females. The sex differences in the length, breadth and area of the foramen magnum are found to be statistically significant. Level of significance in sex differences is however higher ($p < 0.001$) for length and area than the breadth ($p = 0.013$). Statistically significant differences are observed between the area estimated using formula derived by Radinsky and Teixeria in males ($t = 13.388$, $p < 0.001$) and females ($t = 8.083$, $p < 0.001$). Area calculated from the formula used by Teixeria was significantly larger than that estimated using Radinsky's formula. Frequency distribution of anteroposterior diameter, transverse diameter and area of foramen magnum in male and female skulls are shown in Fig. 2. A considerable overlapping of the male-female values is apparent for the different variables analysed in the study.

Predicting equations derived from BLR analysis for the estimation of sex from foramen magnum dimensions and area are shown in Table 2. BLR analysis shows a significant relation between the sex and the length, and the area of foramen magnum ($p < 0.001$). The relation between the sex and the breadth of foramen magnum is not found to be statistically significant ($p = 0.051$). A regression model is derived considering the length and the breadth of foramen magnum together (Table 2). Receiver Operating Characteristic (ROC) curves drawn for the predicted probabilities obtained from BLR analysis from the different variables is shown in Fig. 3. ROC Curve applied to find the predictability of each variable (h, w, A) in sex estimation shows that variable 'h' and variable 'w' have a potential to sex 86.5% and 65.4% skulls respectively. When 'h' and 'w' are considered together in BLR analysis, the predicting potential increases to 88%. The predictability of variable 'A' in sex estimation using the formula derived by Radinsky and Teixeria is 81.6% and 82.2% respectively (Fig. 3).

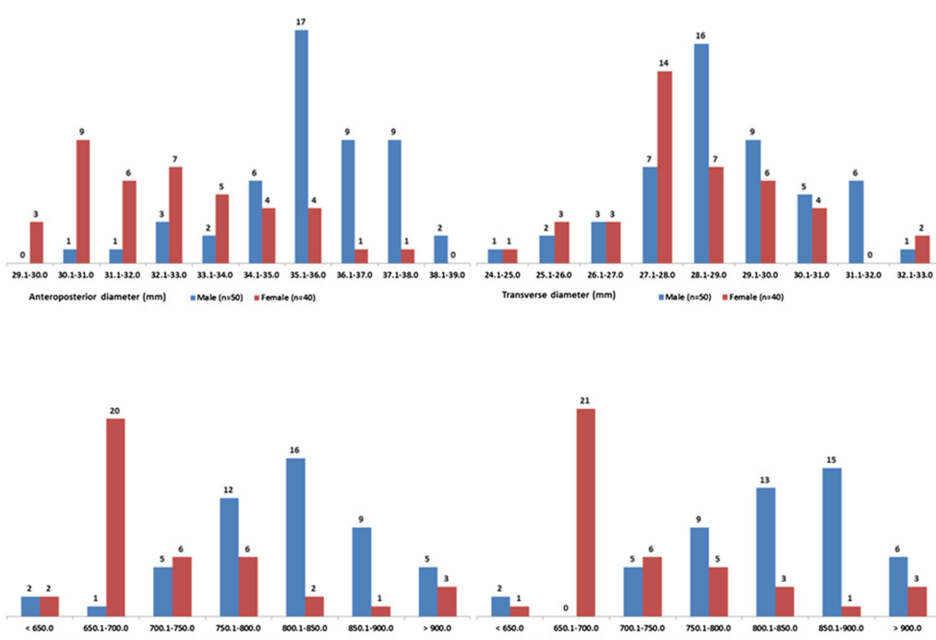

Fig. 2. Frequency distribution of skulls for the Anteroposterior diameter, transverse diameter and the area of foramen magnum.

Table 2
Binary Logistic Regression models for estimation of sex from the measurements of foramen magnum.

Variable	BLR model	Wald	p-value
h	24.552−0.724 (h)	25.253	$<$0.001
w	07.224−0.261 (w)	03.811	0.051
h, w	22.142−0.813 (h) + 0.192 (w)	$h = 21.192$, $w = 1.140$	$h < 0.001$, $w = 0.286$
A (R)	11.571−0.015 (A)	19.410	$<$0.001
A (T)	11.995−0.016 (A)	20.621	$<$0.001

h – Anteroposterior diameter (mm), w – Transverse diameter (mm), A – Area (mm^2), (R) – Radinsky's formula, (T) – Teixeria's formula.

4. Discussion

In the earlier studies conducted exclusively on measurements of foramen magnum in Indian skulls,[17,18] identification points (IP) and demarking points (DP) were used to study the sexual dimorphism of foramen magnum. Routal et al[17] assessed the usefulness of the measurements of the size of foramen magnum in sexing the crania in a study conducted in western part of India. Study of Sayee et al.[18] was aimed at measuring the size of foramen magnum and find out the correlation between area of foramen magnum and endocranial volume in skulls from Karnataka region of southern India. Studies by Routal et al[17] and Sayee et al[18] suggested that the foramen magnum dimensions in males are significantly higher than females. Our findings with regard to significant differences in the mean male and female values of foramen magnum measurements are in accordance with the observations of Routal et al[17] and Sayee et al.[18] Both Routal et al[17] and Sayee et al,[18] however, did not find the foramen magnum measurements as a reliable sexing criteria based on identification points (IP) and demarking points (DP) analysis. Deshmukh and Devershi[19] later in their study conducted on comparison of cranial sex determination in western part of India, did not find the length and breadth of foramen magnum to be reliable in sexing of crania based on univariate analysis. These studies however, do not mention about the sexing accuracy of the foramen magnum measurements.

Gapert et al[5] in a recent study on sex estimation from foramen magnum dimensions in an eighteenth and nineteenth century British sample using discriminant function and regression analysis demonstrated statistically significant differences between male and female skulls. However, the discriminant functions developed in the study predicted correct sex in 70.3% of all cases. Gapert et al[5] thereby concluded that there is limited albeit statistically significant, expression of sexual dimorphism in the foramen magnum region. In other studies reported on sex estimation from foramen magnum measurements, Gruber et al[14] did not find any sexual dimorphism in the diameters of foramen magnum in Central European dry specimen dating from Pleistocene to modern times. In a Turkish population, Gunay and Altinkok[15] observed that mean foramen magnum area in females was significantly lower than males. Their finding in this regard is similar to our observation in the study. They however, based on correlation coefficient analysis concluded that the area is not a useful indicator for sex estimation and that it can be used only as a supportive finding. Uysal et al have

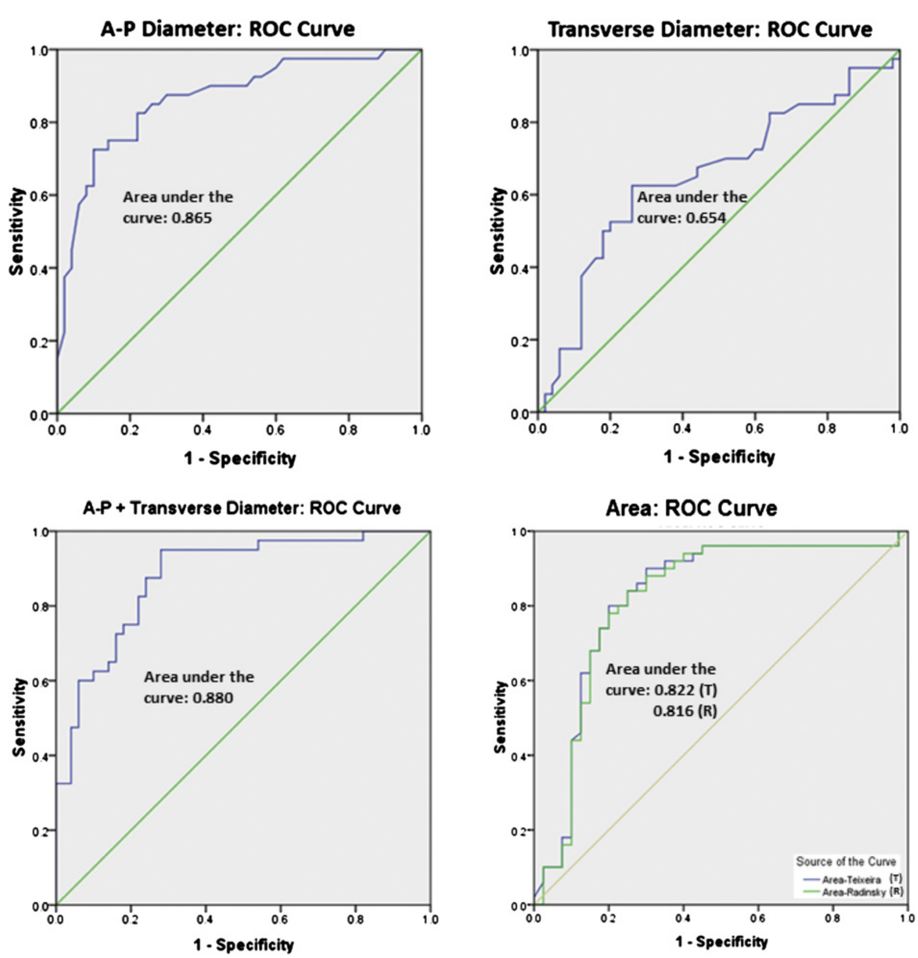

Fig. 3. ROC curve for the Anteroposterior diameter, transverse diameter and the area of foramen magnum.

reported statistically significant sex differences in the width of foramen magnum diameters by using three-dimensional computed tomography (3DCT) measurements.[16] The study used the Fisher's linear discriminant function test and reported that the length and width of right condyle and width of foramen magnum diameters could sex the crania with 81% accuracy.

The present study conducted in a coastal region of southern India utilized Binary Logistic Regression (BLR) analysis for estimation of sex from the foramen magnum measurements and derived regression models for sex estimation. With regard to each dimension of foramen magnum considered individually for its strength in sex determination of the crania, ROC analysis in our study reveals anteroposterior diameter (h) to be the most reliable variable for sex estimation followed by the area (A) of the foramen magnum. Transverse diameter (w) of foramen magnum shows least predictability in sex estimation when compared to the length and area of foramen magnum. The sexing potential increased when length and breadth are considered together in BLR analysis. Study of Gapert et al[5] however, reports the width of foramen magnum to be the most reliable variable in sex estimation. Difference in observations of different authors may be attributed to the differences in the population groups, methodology, and statistical analysis. The mean values of different foramen magnum measurements as reported in earlier studies along with the observations of the present study are shown in Table 3. A variation in the mean values of foramen magnum measurements in males and females is obvious owing to the population differences.

Our findings show that statistically significant differences exist between the areas estimated using formula derived by Radinsky[20] and Teixeria,[13] area calculated from the formula used by Teixeria being significantly larger than that estimated using Radinsky's formula. Our findings in this regard are similar to that shown in the study of Gapert et al.[5] Gapert et al.[5] have used the formula derived by Radinsky and Teixeria for calculating the area of foramen magnum on an eighteenth and nineteenth century skeletal collection. The differences between the areas calculated by different formula however, are apparently smaller in our study when compared to that shown by Gapert et al.[5] Radinsky[20] in his study on mammals reported that endocrinal volume and the area of foramen magnum are adequately correlated. Radinsky's formula derived for the estimation of area of foramen magnum has ben used on human skulls by Routal et al.[17] and Sayee et al.[18] in Indian populations. Teixeria[13] utilized a different formula for area estimation in sex identification from the size of foramen magnum in humans. Variation in the mean values of the area of foramen magnum thus, in addition can be attributed to the different methodologies and formula used to estimate the area of foramen magnum in earlier studies. The fact that Radinsky's formula was not originally derived from human data (but data from five different orders of mammals) means that the accuracy of the areas it produces is unknown. Findley[21] used Radinsky's formula on bats and found that it yielded results different than expected possibly because bats are smaller than the mammals Radinsky had studied. The use of Radinsky' formula by the authors in humans is based on the fact that it is uniformly applied and not used for estimating theoretical variables of a higher order magnitude, like brain size. It needs to be emphasized that while refereeing to certain findings of a study or comparing the findings of a study, similar formula should be used and compared with.

The foramen magnum reaches its original size early in childhood. The limited degree of expression of sexual dimorphism within the foramen magnum dimensions shown in the studies may thus be explained by its early development and maturity. Considering the amount of overlapping in male and female values it can be concluded that the sexing potential of foramen magnum is limited and should be considered only as a supportive finding and its application in sex estimation should be restricted to cases where only a fragment of base of the skull is brought for examination. In such cases, the anteroposterior diameter and area of the foramen magnum can be employed as better tools for sexing the skulls than the transverse diameter of the foramen magnum in the population studied. Small sample size remains the limitation of the study owing to the time bound nature of the research project. However, the paper uses new statistical analysis to draw valid conclusions with regard to sexing of human crania. Similar studies are proposed on larger samples and in different populations to study the sexing potential of foramen magnum in forensic investigations.

Table 3
Comparison of foramen magnum measurements (mean) in various studies.

	h		*w*		*A*	
	Male	Female	Male	Female	Male	Female
Routal et al. [17]	35.5	32.0	29.6	27.1	819.00 (R)	771.00 (R)
Sayee et al. [18]	34.2	33.5	28.5	28.0	–	–
Deshmukh et al. [19]	34.0	34.0	29.0	28.0	–	–
Gapert et al. [5]	35.91	34.71	30.51	29.36	783.82 (R) 862.41 (T)	730.28 (R) 801.78 (T)
Gunay & Altinkok [15]	–	–	–	–	909.91 (T)	819.01 (T)
Teixeira [13]	–	–	–	–	963.73 (T)	805.65 (T)
Present study	35.69	32.57	28.91	28.19	811.67 (R) 821.36 (T)	722.66 (R) 727.31 (R)

h – Anteroposterior diameter (mm), w – Transverse diameter (mm) , A – Area (mm^2), (R) – Radinsky's formula, (T) – Teixeria's formula.

Conflict of interest

None of the authors has any conflict of interest to declare. No source of support in form of grants.

Funding

None.

Ethical approval

None.

Acknowledgments

Authors are grateful to Dr. M. V. Prabhu, Dean, Kasturba Medical College, Mangalore and Professor K. Ramnarayan, Vice-Chancellor, Manipal University, India, for encouraging research and its publication in international journals of repute. We wish to thank Mr. Vasudeva Guddattu, Lecturer, Department of Statistics, Manipal University, Manipal for the assistance in the statistical analysis of the data.

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